Patellar tendinopathy

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Chapter 4

No change in tendon structure on ultrasound tissue characterization following a 4-week exercise program in athletes with patellar tendinopathy

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Abstract

Objectives: The aim of this study was to investigate the effects of a 4-week in-season exercise program of isometric or isotonic exercises on tendon structure and dimensions as quantified by UTC.

Background: Ultrasound imaging is often used to confirm the diagnosis of patellar tendinopathy. A novel imaging technique that enables quantification of tendon structure is Ultrasound Tissue Characterization (UTC). Limited data are available on the effect of in-vivo exercise programs on structural appearance of pathological patellar tendons.

Methods: Volleyball and basketball players (16-31 years) with clinically diagnosed patellar tendinopathy were randomized to a 4-week isometric or isotonic exercise program. The programs were designed to decrease patellar tendon pain. A baseline and 4-week UTC scan was used to evaluate change in tendon structure.

Results: No significant change in tendon structure or dimensions on UTC was detected after the exercise program, despite patellar tendinopathy symptoms improving. The percentage and mean cross-sectional area (mCSA) of aligned fibrillar structure (echo-types I+II) ($Z=-0.414, p=0.679$) as well as disorganized structure (echo-types III + IV) ($Z=-0.370, p=0.711$) did not change over the 4-week exercise program. Change in tendon structure and dimensions on UTC did not differ significantly between the groups.

Conclusion: Structural properties and dimensions of the patellar tendon on UTC did not change after a 4-week isometric or isotonic exercise program for athletes with patellar tendinopathy in-season, despite an improvement of symptoms. Possible explanations for this are provided.

Introduction

Patellar tendinopathy (jumper's knee) is an overuse injury of the patellar tendon that impacts on sport and work participation.[1,2].The clinical diagnosis of patellar tendinopathy is often confirmed with ultrasound imaging, which has been shown to be relatively accurate in confirming patellar tendinopathy.[3] However, conventional grayscale ultrasound has limited ability to measure tendon dimensions and monitor intra-tendinous changes in response to load. Only relatively gross measures such as cross sectional area, anterior-posterior diameter, and height and width of a hypoechoic zone can be measured. It is not possible to quantify tendon structure with conventional ultrasound.

Higher level analysis of ultrasound images has enabled quantification of tendon structure.[4,5] A relatively new imaging technique specifically designed for tendon is ultrasound tissue characterization (UTC, UTC imaging, Stein, The Netherlands). UTC provides a detailed view of a tendon in all planes and quantifies tendon structure by measuring stability of pixel brightness over contiguous transverse gray-scale images. UTC has been developed in veterinary medicine and tested against histomorphology of equine tissue.[6] It has also been found to reliably quantify the stability of the echo-pattern in the human Achilles tendon and symptomatic tendons can be distinguished from non-symptomatic tendons using UTC.[7] UTC may be able to detect more subtle changes in tendon structure than conventional ultrasound.[8,9]

Exercise-based treatment has the most evidence in the management of patellar tendinopathy.[10] The impact of exercise on tendon structure has not yet been elucidated. It has been shown that a pro-peptide marker of type I collagen in the peritendon is elevated after a single bout of exercise (three hours of running)[11] as well as after a heavy resistance eccentric rehabilitation program of 12 weeks.[12] However, whether an increased type I collagen formation will lead to an adaptation in tendon structure is unclear, as tendon cells also have a capacity to prevent collagen fibrillogenesis within a cell.[13] Limited data are available on the effect of in-vivo exercise programs on structural appearance of the patellar tendon in patients with patellar tendinopathy. Only one other study has investigated the effect of exercise on patellar tendon dimensions in patients with patellar tendinopathy.[14] Doppler area and thickness of the patellar tendon decreased after a 12-week heavy slow resistance exercise program, but were not affected by a 12-week isolated eccentric exercise program. The effect of exercise programs on patellar tendon structure has not been investigated so far. Therefore, the aim of this study was to investigate the effect of a 4-week in-season exercise program on the structure and dimensions of the patellar tendon as quantified by UTC. This study investigated whether two exercise programs (isometric and isotonic exercises), designed to decrease patellar tendon pain, affected tendon structure or dimension on UTC.

Methods

Design & Participants

Volleyball and basketball players (16-31 years) presenting with patellar tendinopathy who were training or playing at least three times per week were eligible for this study. Inclusion and exclusion criteria are presented in Table 1. The participants took part in a larger randomized clinical trial investigating the difference in effect on pain between an in-season 4-week isometric and an in-season 4-week isotonic exercise program. Detailed procedures of this trial have been reported elsewhere (van Ark et al., unpublished; Rio et al., unpublished). Before and after the exercise program, UTC scans of the patellar tendon were made. Written informed consent of participants was obtained before inclusion in the study and rights of the participants were protected. The study was approved by the Monash University Human Research Ethics Committee (MUHREC), Australia (CF12/0230 – 2012000067) and it was registered in the Australian New Zealand Clinical Trial Registry (ACTRN12613000871741).

Table 1. Inclusion and exclusion criteria

Inclusion criteria

- Patellar tendinopathy diagnosed by an experienced physiotherapist
- Focal pain at inferior or superior pole of the patella
- History of exercise associated knee pain
- Training or playing at least three times per week

Exclusion criteria

- Other knee pathology
- Previous patellar tendon rupture
- Previous patellar tendon surgery
- Inflammatory disorders
- Metabolic bone diseases
- Type II diabetes
- Use of fluorquinolone antibiotics or corticosteroids in last 12 months
- Known familial hypercholesterolemia
- Chronic pain conditions

Exercise programs

All exercises in both groups were performed on a leg extension machine. Five sets of 45 second single leg isometric holds were performed for both legs in the isometric exercise group during each session. The knee joint angle during the exercises was 60 degrees and contractions were executed at 80% of the maximal voluntary contraction weight.

The participants in the isotonic exercise group had to perform 4 sets of 8 repetitions single leg isotonic contractions for each leg per session. A repetition of an isotonic contraction started with a three second concentric phase followed by a four second eccentric phase. Exercises were performed in a pain free range between 10-90 degrees of knee flexion at 80% of 8 repetitions maximum.

A set of exercises for both legs was followed by a rest interval of 15 seconds. Weights were increased by 2.5% every week if correct weight was available on the leg extension machine, if pain free and if no shaking of the muscles during the exercises took place. When participants experienced pain during an exercise or when their muscles started shaking, they were instructed to complete the session with a lower weight for the following repetitions. This ensured an equal time under tension for both groups. In addition to face-to-face explanation and instruction of the exercises by a physiotherapist at the gym, participants received an audio file with real-time instructions of the exercises and rest intervals to listen to during their exercises.

Outcome measures

UTC

A UTC scanner consists of an ultrasound probe (SmartProbe 10L5, Terason 2000; Teratech) secured in a tracking device (UTC Tracker, UTC Imaging) to ensure a consistent transducer tilt angle in relation to the tendon. The tracker device moves the ultrasound probe automatically with a constant speed perpendicular along the tendon long axis. An ultrasound image of the transverse plane of the tendon is captured every 0.2 mm over the length of the patellar tendon. The UTC software (UTC 2011, UTC Imaging) constructs the sagittal and coronal planes from the transverse images creating a 3D ultrasound data-block.[7]

Participants were scanned by one trained researcher (SD). The worst knee of participants (most pain on NRS (0-10) during single leg decline squat (SLDS)) was scanned.[15] Participants lay supine on a treatment bench; their knee was bent to approximately 100˚ of knee flexion in which a clear image could be obtained with the ultrasound probe in the tracker perpendicular to the long axis of the tendon. Based on the consistency of intensity and distribution of gray levels of images over 4.8mm (25 images), four echo-types were created using computer algorithms. Echo-type I: intact and aligned tendon bundles; echo-type II: less integer and waving tendon bundles; echo-type III: mainly fibrillar tissue; echo-type IV: a mainly amorphous matrix with loose fibrils, cells or fluid.[4,7] A single ultrasound reflection that typically belongs to one interface structure is displayed as echo-type I or II (referred to as aligned fibrillar structure in this paper). Multiple reflections which interfere because of multiple interfaces are displayed as echo-types III and IV (referred to as disorganized structure in this paper).

Prior to analysis, the scans were de-identified to ensure the researcher was blind to participant and date of measurement. The tendon was analyzed over 30 mm starting from the disappearance of the apex of the patella. This region was selected as it coincides with the most common area of pain and pathology. Contours were manually selected around the border of the patellar tendon on the transverse images at regular intervals (no more than 5mm apart) over the length of the tendon. A consensus on the placement of contours between two experienced researchers (MvA and SD) was reached. Based on these contours, the UTC software (UTC 2011, UTC Imaging) interpolated these defined contours to create a complete tendon volume where the proportions of each echo-type and total number of pixels were calculated. The percentages of each echo-type in the region of interest were calculated. Mean cross-sectional area (mCSA) of aligned fibrillar structure (echo-types I and II) and disorganized structure (echo-types III and IV) were calculated as well. UTC software provides the number of pixels and percentage of each echo-type for every transverse image. The CSA for each transverse image was calculated by multiplying the number of pixels by the area of the pixel (0.011mm^2). The volume (mm^3) of aligned fibrillar structure, disorganized structure and total tendon was calculated and divided by 30mm to provide the mCSA (mm^2) for all parameters. This method has been described by Docking and Cook[16] and has been validated against an ultrasound phantom of known volume. Furthermore, maximum thickness (anterior-posterior diameter) of the patellar tendon was recorded.

Clinical outcome measures

Severity of patellar tendinopathy symptoms was quantified by pain measured with a numeric rating scale (NRS; 0-10) during a SLDS and the Victorian Institute of Sport Assessment – Patella (VISA-P) questionnaire. The single leg decline squat is a provocative clinical test that loads the patellar tendon in order to evaluate pain response of the patellar tendon.[15,17,18] The VISA-P questionnaire is specifically designed to evaluate severity of symptoms, knee function and ability to participate in physical activity in athletes with patellar tendinopathy.[19] It provides a score between 0 and 100, with a score of 100 representing a pain free and fully functioning athlete. Clinical outcome data – NRS pain (0-10) during the SLDS pre and post exercise program and VISA-P – are reported in a separate paper describing the clinical outcomes of this trial (van Ark et al, unpublished). Participants were also invited to be involved in a transcranial magnetic stimulation (TMS) sub-study. Furthermore, the immediate effects of the exercises are reported in a paper using the NRS pain score before and after every exercise session (Rio et al, unpublished). As the focus of the current paper is on tendon structure and dimensions, clinical outcomes will only briefly be mentioned in the results. The effect of these exercise programs on tendon structure and dimensions is important for the understanding of adaptation of the patellar tendon in response to treatment of patellar tendinopathy, and adds important information beyond the clinical outcome data.

Data analysis

As outcome measures were not normally distributed, Wilcoxon signed-rank tests were used to test for differences in the UTC echo-types, mCSA, thickness, NRS-pain during SLDS and VISA-P between baseline and follow-up measurements. A Mann-Whitney test was used to compare change in UTC outcome measures (UTC echo-types, mCSA and thickness) between the isometric and isotonic group.

Results

Participants were recruited by flyers including the most important inclusion criteria and by talking to teams playing or training three times per week. All athletes with patellar tendinopathy who were examined by the researchers matched the criteria and consented to participate in the trial. The number of athletes excluded from the study due to the presence of other knee injuries was not recorded. A total of 29 participants were included in the trial after the recruitment period, including participants with quadriceps tendinopathy at the superior pole of the patella. However, with current UTC techniques it is not possible to obtain a scan with sufficient quality of the quadriceps tendon superior to the patella. Therefore, no UTC scans could be obtained from three participants and these were excluded from the analysis (Figure 1). A flow chart of athletes with patellar tendinopathy participating in the study is presented in Figure 1. Participants were 16 men and 2 women with a mean (± SD) age of 22.7 (±4.7) years (range 16-31). Mean (± SD) BMI of the participants was 24.7 (±3.1) kg/m^2 (range 20.4-34.7).

All outcome measures of the UTC scans did not show significant changes between baseline and follow-up measurements, with none of the parameters greater than previously reported minimum detectable differences (Table 2).[16] There was no significant difference between the isometric and isotonic group for the change in echo-type I (U=28.0, p=0.286), echo-type II (U=29.0, p=0.328), echo-type III (U=33.0, p=0.534), echo-type IV (U=39.0, p=0.929), aligned fibrillar structure (U=33.5, p=0.563) and disorganized structure (U=33.0, p=0.534). Similarly, there was no significant change in mCSA of aligned fibrillar structure (U=35.0, p=0.657), mCSA of disorganized structure (U=34.0, p=0.594), mCSA (U=39.0, p=0.929) and tendon thickness (U=31.0, p=0.421) between groups. No difference in clinical outcomes between the groups after the 4-week exercise programs were found as well (van Ark et al, unpublished). A significant decrease in NRS-pain during the SLDS of (median (IQR)) 6.0 (4.0-6.3) to 2.0 (1.5-3.5) was found after the 4-week exercise program compared to baseline (Z=-3.634, p<0.001) (van Ark et al, unpublished). The VISA-P questionnaire showed a significant improvement after 4 weeks, from (median (IQR)) 68 (57-76) to 82 (73-88) (Z=-3.112, p=0.002) (van Ark et al, unpublished).

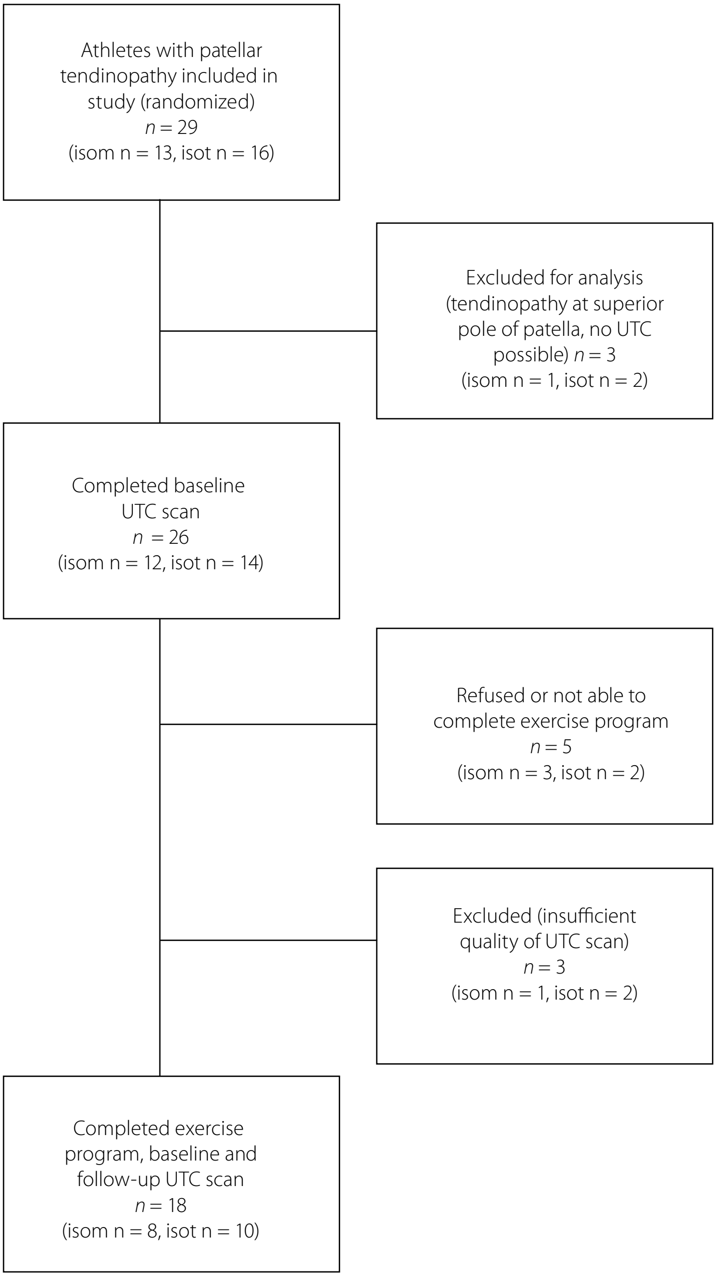

Figure 1. Flow chart of athletes with patellar tendinopathy participating in the study (isom = isometric group, isot = isotonic group)

Table 2. Tendon structure and dimensions measured on UTC before and after a 4-week isometric or isotonic exercise program in athletes with patellar tendinopathy *(n=18)*

	Total population			**Isometric exercise group**			**Isotonic exercise group**		
	Baseline median (IQR)	**4 weeks median (IQR)**	**Wilcoxon signed rank test. Z and p-value**	**Baseline median (IQR)**	**4 weeks median (IQR)**	**Wilcoxon signed rank test. Z and p-value**	**Baseline median (IQR)**	**4 weeks median (IQR)**	**Wilcoxon signed rank test. Z and p-value**
Echo-type I %	73.1 (64.1-83.5)	75.8 (64.4-79.0)	z =-.893 p=.372	72.7 (65.2-83.6)	74.8 (60.9-79.7)	z=-1.540 p=.123	73.1 (63.9-83.8)	75.8 (68.8-78.9)	z=-.153 p=.878
Echo-type II %	16.3 (11.2-20.9)	17.4 (15.5-18.9)	z=-1.459 p= .145	18.1 (11.4-23.3)	18.6 (17.0-26.9)	z=-1.540 p=.123	14.0 (10.6-20.2)	15.7 (13.4-18.3)	z=-.561 p=.575
Echo-type III %	4.3 (2.4-7.3)	4.2 (2.9-6.6)	z=-.142 p=.887	4.6 (1.6-4.7)	3.4 (1.4-7.5)	z=-0.338 p=.735	3.8 (2.7-8.2)	4.9 (3.0-6.6)	z=-.375 p=.721
Echo-type IV %	4.4 (2.5-6.5)	3.7 (2.1-5.9)	z=-1.570 p=.116	2.7 (2.1-6.2)	3.2 (1.1-4.8)	z=-1.260 p=.208	4.5 (3.3-7.5)	3.8 (3.0-7.3)	z=-.971 p=.332
Aligned fibrillar structure (Echo-type I + II %)	92.4 (86.9-95.0)	92.4 (87.7-95.0)	z=-.981 p=.327	92.7 (89.1-96.5)	93.5 (87.8-97.4)	z=-.491 p=.624	91.8 (85.2-93.7)	91.3 (87.0-94.2)	z=-.968 p=.333
Disorganized structure (Echo-type III + IV %)	7.7(5.0-13.2)	7.7 (5.0-12.4)	z=-.980 p=.327	7.3 (3.5-10.9)	6.6 (2.7-12.3)	z=-.491 p=.624	8.2 (6.3-14.7)	8.8 (5.8-13.0)	z=-.968 p=.333
Mean CSA of Aligned fibrillar structure (mm^2)	121.5 (110.2-133.1)	124.3 (112.2-136.1)	z=-.414 p=.679	122.5 (112.1-131.5)	119.1 (112.1-128.6)	z=-.560 p=.575	121.5 (108.1-133.4)	124.9 (116.9-139.2)	z=-.357 p=.721
Mean CSA of disorganized structure (mm^2)	10.9 (7.3-20.7)	11.4 (6.4-21.9)	z=-.370 p=.711	9.9 (4.9-19.1)	9.6 (3.0-21.1)	z=0.0 p=1.0	11.9 (8.4-22.8)	12.4 (7.4-21.9)	z=-.357 p=.721
Mean CSA (mm^2)	138.3 (126.3-145.9)	140.7 (117.3-153.5)	z=-.414 p=.679	137.1 (121.6-145.4)	128.4 (116.2-154.5)	z=-.280 p=.779	140.5 (128.7-145.9)	145.1 (127.0-154.7)	z=-.459 p=.646
Thickness – anterior-posterior diameter (mm)	7.8 (6.9-8.6)	7.5 (6.5-9.1)	z=-.131 p=.896	8.1 (7.3-9.0)	8.9 (6.6-9.6)	z=-.422 p=.673	7.4 (6.4-8.4)	7.4 (6.4-8.0)	z=-.102 p=.919

Significant difference from baseline (p<0.05), IQR = interquartile range, CSA = cross sectional area

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Discussion

Tendon structure, thickness and mean cross sectional area on UTC were not altered after a 4-week isometric or isotonic exercise program despite a significant decrease in pain. This is the first study to investigate the effects of a patellar tendinopathy treatment on patellar tendon structure with UTC.

The effect of treatments on patellar tendon structure and dimensions is still unclear. Although presence of ultrasound abnormalities increases the risk of developing patellar tendinopathy,[20–24] pain and ultrasound abnormalities do not have a one-to-one relationship.[25] Results of previous studies are inconclusive regarding the relationship between clinical outcomes and ultrasound changes in lower limb tendinopathies.[14,26–28] Only one in-vivo study on the effects of treatments on patellar tendon dimensions has been conducted in patients with patellar tendinopathy. This was a randomized controlled trial conducted by Kongsgaard et al, [14] which compared corticosteroid injections, isolated eccentric training and heavy slow resistance training in 52 recreational athletes with patellar tendinopathy. They found a decrease in anterior-posterior tendon diameter and color Doppler area in the heavy slow resistance and corticosteroid group after 12 weeks compared to baseline. Despite a similar decrease in pain between all groups, no change was found in the eccentric group. Patellar tendon cross sectional area was only increased in the eccentric training group.

Our results are in line with those of a prospective observational study of 23 chronic Achilles tendinopathy patients undertaking an eccentric training program.[5] UTC echo-types did not change from baseline over the course of the 24 week training program, despite clinical improvement observed. They concluded that there was no short-term (24 weeks) increase in organized tendon structure after eccentric exercises.[29] In contrast, an improvement in tendon structure on UTC was observed in 54 Achilles tendinopathy patients receiving either platelet-rich plasma (PRP) injection or placebo (saline) injection both combined with eccentric exercises. Tendon structure on UTC showed improvements in echo-types I+II and coincided with a significant decrease of echo-type III and IV after 24 weeks.[30] However, the change in UTC echopattern was no different between the two groups. The changes in tendon structure on UTC seem to be related to the improvement in pain and function of these patients.[31] The previous two UTC studies show contradictory evidence on the relation between clinical outcome and tendon structure on UTC. Results from our study support the theory that a decrease in pain does not necessarily mean a coinciding improvement in patellar tendon structure in the short term.

There are several possible explanations for the absence of an effect on structure in our study. One of the explanations is that changes in tendon structure take longer than 4 weeks to occur. Markers of anabolic and catabolic processes in the peri-tendon are in balance for the first 4 weeks of physical training, whereas after 4 weeks a net collagen synthesis occurs.[32] However, changes to the tendon structure may not follow, tendon structure might take many months to improve[26,33] if structure changes at all.[28] This is confirmed by Heinemeier et al. who demonstrated that levels of the radioisotope ^{14}C in the core of Achilles tendons corresponded to atmospheric ^{14}C levels during the first two decades of life among people living in regions where nuclear bomb testing occurred; in contrast hardly any ^{14}C was present in muscle samples.[34] The authors therefore concluded that renewal of adult core tendon tissue is extremely limited.[34] Due to end of the season, participants have not been followed up over a longer period. Future research should investigate the effects over a longer period and the effects of longer exercise programs.

Another possible reason for the limited change in tendon structure observed in this study is that the tendon adapts to pathology by ensuring that sufficient levels of load-bearing aligned fibrillar structure is present.[16] Docking & Cook[16] compared the mCSA of aligned fibrillar structure on UTC (echo-types I and II) in the pathological and structurally normal patellar tendon. Interestingly, an increased mCSA of aligned fibrillar structure was observed in the pathological patellar tendon. The mCSA of aligned fibrillar structure in our study is similar to that reported in the structurally normal tendon.[16] It was proposed that as the pathological patellar tendon contains sufficient levels of aligned fibrillar structure, remodeling of tendon structure is not required to obtain a positive clinical outcome. Moreover, Docking & Cook[16] suggested that exercise based interventions may be efficacious by building load tolerance in the already present aligned fibrillar structure, improving muscular strength and capacity and/or changes to the central nervous system.[35] The findings of the current study seem to support the hypothesis that structural improvements are not required for a positive clinical outcome as the tendon may already have sufficient levels of load-bearing aligned fibrillar structure. Future interventions may therefore need to focus on addressing load capacity in the surrounding aligned fibrillar structure, rather than normalizing tendon structure.

The total mCSA of the patellar tendons in our study is smaller (138.3 mm^2) compared to previous reported mCSA of pathological tendons (154.9 mm^2).[16] Docking & Cook[16] reported a relationship between the mCSA of disorganized tissue (echo-type III + IV) and total tendon mCSA. This may explain the difference in mean cross sectional area, because they reported a higher amount of disorganized structure compared to our study (median of 17.1mm^2 compared to 10.9mm^2 at baseline in our study).[16] The difference in population of the studies may potentially have caused these differences; our study included an active sporting population with patellar tendinopathy, while the previous study was a clinical cohort.

Our study is one of the first studies presenting UTC characteristics of patellar tendinopathy patients. Only recently, the first results of UTC data in patellar tendons were presented.[16,36] Different versions of the UTC (with a different ultrasound probe: SmartProbe 12L5-V or SmartProbe 10L5), populations and characteristics of the studies make it hard to compare absolute values. It is important to realize that these features may influence UTC results. Therefore, characteristics of UTC scans should always be reported in research as well as clinical practice.

This study contributes to the discussion on the relationship between clinical outcomes and tendon structure in patellar tendinopathy. However, many issues around this subject are still not elucidated. For a better understanding of patellar tendinopathy, studies on long term effects of treatments on tendon structure should be conducted. More research has to be conducted in this field to be able to make grounded statements on this topic. The current study provides some rationale as to why positive clinical outcomes are possible with limited tissue regeneration. Future studies may also need to investigate other parameters (i.e. muscle strength and endurance, corticospinal changes) to explain potential positive clinical findings following load-based interventions.

Conclusion

A 4-week isometric or isotonic exercise program for patellar tendinopathy does not have an effect on tendon structure and dimensions quantified by UTC. Despite an improvement in patellar tendinopathy symptoms after the exercise program, tendon characteristics on UTC did not change accordingly within a 4-week timespan. This study supports that pain reduction does not necessarily mean a coinciding improvement in patellar tendon appearance.

Findings

Structural properties and dimensions of the patellar tendon on UTC do not change after a 4-week isometric or isotonic exercise program for athletes with patellar tendinopathy in-season, despite a decrease in symptoms.

Implications

Outcomes of treatments for patellar tendinopathy need to be based on clinical findings rather than imaging. More research is needed to determine the effect of treatments on tendon structure.

Caution

This study only reports short term effects of isometric and isotonic exercise on tendon structure. Effects of exercise programs of a longer duration and with longer follow-up periods need to be investigated.

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